Using 'off the shelf ideas' to plan and design a unit of work in STEM.

ABSTRACT

Primary and Early Years settings have had insufficient access to resources and professional development to integrate STEM education as part of a curriculum program. The aim of this case study was to explore the understanding and transformation required to modify a commercial STEM resource into a curriculum plan that addressed real-world issues grounded in the Sustainable Development Goals. This small-scale action research used interviews, document analysis, questionnaires and group discussions to examine the subject knowledge required across the disciplines to plan and teach a STEM-focused curriculum. Lee Shulman's 'Model of Pedagogical Reasoning and Action was used as a theoretical framework' to reflect on the curriculum plan. My findings show that a commercially prepared plan provided a valuable scaffold enabling practitioners to consider the content and pedagogical knowledge required for a STEM-focused curriculum. The contribution of subject specialists during the planning process enabled the interdisciplinary approach to create a STEM plan.

KEY WORDS: *STEM, primary education, Sustainable Development Goals, pedagogical reasoning and action, subject knowledge, curriculum design, interdisciplinary, inquiry based.*

Introduction

The aim of this paper is to examine the position of STEM within primary education and explore practitioners' understanding of 'STEM education'. The acronym STEM is usually applied to describe professional practices in the areas of Science, Technology, Engineering and

Mathematics that come together as a collective discipline (Comptroller and Audit General, 2018; Bell, 2016). In this paper I will debate the definition and perception of STEM education and how practitioners apply this knowledge when designing STEM learning for primary school children. I will delve deeper into the interdisciplinary nature of teaching STEM, and examine the role of the Sustainable Development Goals (SDG) as a mechanism that is able to connect the four subjects. I will consider some barriers that primary practitioners encounter when embedding STEM education in primary school settings. I utilised Lee Shulman's model of 'Pedagogical Reasoning and Action' (1987) as a framework for my action research study. I will describe the process, as outlined in Shulman's model and how the stages within the process were used during the research.

Developments and progress in 'STEM education' have been influenced by a range of factors to include the economy, politics and globalisation. Since the early 2000s, various government reports have elicited growing concerns about the supply of STEM skills in the workforce (Roberts, 2002; HM Government, 2017). In education, the declined interest in some STEM subjects, such as mathematics and science, have shown to have a direct correlation to the STEM skill shortage (DFES, 2004; DFE, 2010). Over time, this has generated the widely held belief that one of the UK's key economic problems is a shortage of highly qualified scientists, technologists, engineers and mathematicians to 'compete in an era of globalisation' for which science and innovation systems are central (Sainsbury, 2007, p.3; Bell, 2016 p.62; Morgan et al., 2016). Although there has been much debate on the extent and accuracy of the STEM skills shortage (Comptroller and Audit General, 2018; Williams, 2011; McGarr and Lynch, 2015; Smith and White, 2015); the government has responded with a range of initiatives and policies that are aimed at raising young people's participation in the STEM subjects.

The aim of this paper is not to debate the potential STEM crisis; the above offers some explanation of why STEM has filtered in the education system at all levels, and not just in

Higher Education (HE). It is the filtration of STEM in primary education that has driven the interest of this paper. Blackley and Howell (2015) discuss how the rise of 'STEM education' did not result in any meaningful changes to teaching practices or student outcomes because of the absence of educators from the planning and strategising of the approach. They associated two reasons for the lack of success of STEM in education; curriculum structure and preparation of teachers. Although some studies and research have explored teacher perceptions and aspects of STEM, such as engineering in UK schools (Bell, 2016; Clarke and Andrews, 2010), there is limited understanding of how to successfully integrate STEM education into primary settings and how best to nurture the profile of STEM across the primary curriculum, an issue which remains a national priority for the government (Smith, 2017; ACME, 2011).

What is STEM?

Barriers to understanding STEM begin with the awareness that there is no universal definition of what should be counted as STEM, in the workplace or education (Comptroller and Audit General, 2018). Although the acronym is easily understood, the essence of STEM and how it translates in a classroom or learning situation is a challenging concept. Williams, attributes this uncertainty to a lack of clarity behind the rationale and logic of combining the four disciplinary subjects (2011; Wong, Dillon and King, 2016). The Report by the Comptroller and Auditor General (2018) found there to be a variety of perspectives on understanding STEM from recognising it as separate, distinct subjects to a combination of some or all four subjects. The Report discusses further the complexity of STEM and an overlapping group of subject areas that can be defined in several ways depending on the criteria used. As the STEM agenda has primarily been one of the vocational and economic goals (Blackley and Howell, 2015), the unstable, and inconsistent definition of STEM has permeated into education.

Further challenges to understanding STEM in education is the alignment of STEM to the subjects in the National Curriculum (NC). Examples include defining the term ‘Technology’ and understanding how to interpret ‘Engineering’ which, does not exist as a subject in the NC. What emerged, as a result, was an enhanced focus on mostly science-based topics with some mathematics and an unfamiliarity of the critical role that, ‘engineering’ and technology have in developing design and problem-solving skills and innovative ways of learning across the disciplines (Blackely and Howell, 2015, p.104; McDonald, 2016). Williams (2011) summaries the ambiguities surrounding the amalgamation of STEM as being driven by economic and vocational goals and built on a political ideology that sees education as a servant to the economy. What research and studies have shown is the mere definition and idea of STEM is confusing and perplexing even to those who use it (Bell, 2016). Despite this, the discourse of STEM is found widely in education and the problems faced by teachers is that they are trying to integrate STEM for which an educational rationale is absent and hinders a collaborative approach (Williams, 2011).

Given the ambivalence around the concept of STEM, recent research and studies have attempted to offer an elucidation of the acronym. Hernandez et al. (2014) characterised an ‘authentic STEM education’ as one that developed conceptual knowledge of the ‘inter-related nature of science and mathematics’ to allow for an understanding of engineering and technology (cited in McDonald, 2016, pg. 531). Balka offers a similar explanation describing STEM literacy as, ‘the ability to identify, apply and integrate concepts from science, technology, engineering and mathematics to understand complex problems and to innovate to solve them” (2011, pg. 7, cited in McDonald, 2016). In addition, the STEM Task Force Report (Torlakson, 2014) included the importance of the application of knowledge and skills learned in two or more STEM disciplines to real-world problems as a means to deepen understanding. The above interpretations of STEM vary in intensity of the integration of the four subjects. For teachers, the challenge is to comprehend a model of STEM and consider how it may appear when enacted in the classroom. I refer to the interdisciplinary nature of the STEM subjects later in this paper. However, it is worth noting that teaching STEM requires a curriculum structure that positions itself away from the teaching of individual subjects.

Practitioners' understanding of STEM in education.

One of the recommendations that emerged from the review of STEM interventions, based on research evidence carried out by Rosicka (2016) indicated the importance of professional development within the STEM disciplines. This point is further supported by other research and studies that identify the significance of education for teachers on STEM-related issues to include developing subject knowledge, support networks and resources to enable the learning and teaching of a STEM-focused curriculum (Blackley and Howell, 2015; Nadelson and Seifert, 2017; Bell, 2016; Clarke and Andrews, 2010). What has transpired across the studies is that knowledge and academic background in the STEM subjects is strongly linked to the capacity to teach these subjects with confidence and passion. An example of how to raise the profile of STEM in education can be taken from the Australian government who have introduced various efforts to ensure schools are supported by specialist teachers in STEM disciplines and that senior management teams are educated to be leaders in STEM. The model of support for teachers of STEM, provided by the Australian government, prioritise teacher professional development programmes in science, technology and mathematics, which are considered to be essential to the knowledge teachers require for STEM education (Prinsley and Johnston, 2015).

However, having specialist teachers in STEM disciplines is not enough. One of the most significant educational challenges for STEM education is that very few guidelines and models exist for teachers to follow on how to teach STEM in an 'integrated' manner in their classrooms. Research carried out by Boe et al. (2014) indicate that the four discipline areas are often taught in a disjointed manner, failing to integrate STEM in a unified way. What emerged from their study was that teachers required a greater understanding of how the four disciplines come together to form STEM when planning and teaching. This was further supported in a study carried out by Roehrig et al. (2012) who found that when individual teachers planned for STEM, the content areas depended on the primary subject area of the teacher. Having a depth of knowledge in one subject was not enough to design a STEM curriculum as it often led to rudimentary links and connections to other disciplines where subject knowledge was not as secure. Bell (2016) adds to the argument by stating that a STEM-focused curriculum required a change in the pedagogical approach with a focus on 'learning to do something with the knowledge acquired'. The goal of which would be to foster greater connections with '21st Century' learning skills and investigate authentic, real-world problems (McDonalds, 2016).

Interdisciplinary nature of STEM for learning and the Sustainable Development Goals

The definitions of STEM, as shared above, and the nature of how STEM requires to be taught, position the learning and teaching that strongly advocates for an interdisciplinary approach to curriculum planning and teaching. An interdisciplinary approach to the curriculum considers the integration of subjects that generate an understanding of themes and ideas. This also includes connections between different disciplines and their relationship to the real-world. Students learning this way can apply knowledge gained in one discipline to another discipline as a way to deepen the learning experience and as such, encourage creativity, meta-cognition and contextualise learning to real-world issues. A study on 'The Nature of Problem Solving' commissioned by OECD, outlined the importance of problem-solving, improving complex thinking and analytical skills as being essential to learning at every stage of development (2017). Learning factual knowledge and the ability to apply, analyse and create new knowledge go hand in hand (OECD, 2017). Roehrig et al. (2012) further argue the point that in the real world, problems are not separated into isolated disciplines. In an increasingly ever-changing global society, an integration of multiple STEM concepts and skills are required to solve problems. The artificial separation of subjects can limit learning as well as alienate the learner from real-world issues, whereas an interdisciplinary approach to the curriculum provides more meaningful learning experiences.

To fully engage and promote student engagement and progress in STEM, teacher subject knowledge and teaching practices require a shift from traditional, teacher-centred methods of teaching towards strategies that emphases and encourage greater active student-centred approaches. Previous studies that have explored aspects of STEM education report the importance of an inquiry-based approach to learning and teaching (Roehrig et al.. 2012; Rosicka, 2016; Bell, 2016). Such an approach advocate practices that enable students to engage with 'higher-order thinking skills' and engagement with real-world problems through developing students' ability to 'ask questions; design investigations, solve problems, interpret data and evidence, form explanations and arguments and communicate findings' (McDonald, 2016 pg. 538).

The positioning of the SDGs, as set by the United Nations (UN), offer a route that instigates the adoption of an interdisciplinary approach, as required with STEM, and address real-world problems. Sustainable development has been defined as development that, 'meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987 p.43). The UN acknowledged the 17 SDGs in 2015 intending to end poverty, protect the planet, ensure sustainable consumption, innovation, peace and justice. The fourth

SDG specifically focused on promoting quality education as a means of advancing sustainable development, as well as placing education at the heart of the strategy.

Annan-Diab and Molinari (2017) discuss the importance of how ‘interdisciplinarity’ (p. 4) increases our knowledge of understanding complex real-world problems and provide solutions that integrate expert knowledge from different disciplines. The authors further argue that adopting an interdisciplinary model when addressing the SDGs can enable a ‘cognitive advancement’ which would explain a phenomenon, solve a problem, create a product or raise new questions (p. 5). The limitations and barriers, however, to instigate an inquiry and problem-based approach include an education assessment model that discourages teachers from trying new ideas and holding teachers accountable for minimum grades in standardised tests. The narrowing of a curriculum due to a focus on a few measurable outcomes has had some negative consequences on the ‘quality of education’ and the teaching of subjects that ‘mirror test-related content’ (Ofsted, 2019 pg. 5). Insufficient time to develop an integrated curriculum and teachers having a limited knowledge base to know how to demonstrate interconnectedness between subjects further hinders progress for the teaching of STEM in primary school settings.

A theoretical framework for action-based research

Action research in education is research undertaken by practitioners in order that they may improve their practices. It involves a spiral of self-contained cycles of planning, action, evaluation and reflection, and based on gathered evidence, changes in practice are implemented (Koshy, 2009). The fundamental aim of action research is to improve by exploring and theorising practice to generate knowledge (McAteer, 2013). The process often involves a series of linked enquiries with teachers formulating questions arising directly from their classroom experiences at each stage in the process (Baumfield et al. 2013).

The use of action research owes much to the work of Lawrence Stenhouse, whose idea of 'the teacher as a researcher' involved the practitioner engaged in a systematic study of the work with other practitioners and the testing of ideas through classroom research (Elliot, 2015, pg. 4). Stenhouse's theory of education placed the teacher as being central to education, giving greater value to teacher professionalism, autonomy and development (Skilbeck, 1983). He suggested that the work of teachers should be researched by teachers themselves as well as being supported and guided by professional researchers who would also choose the focus for the research (McAteer, 2013). The kind of knowledge that was of interest to Stenhouse was 'pedagogical knowledge in the form of structures, concepts, processes and procedures teachers needed in order to fulfil their educative role' (Skilbeck, 1983 pg. 12). In the context of the work carried out by Stenhouse, on curriculum development, he believed research contributed to the development of knowledge through systematic and 'self-critical' enquiry.

Although several models for action research have been put forward, I decided not to use a particular model too rigidly. Instead, I applied Lee Shulman's theoretical framework of 'pedagogical reasoning and action' as an evaluative and reflective tool. As this study primarily set out to explore the development of knowledge that emerged from the use of a commercial STEM resource, employing a theoretical framework that was focused on enhancing pedagogical knowledge seemed most appropriate.

Shulman describes pedagogical knowledge as a transformation of the content and subject knowledge required for teaching. The act of transformation involves the representation of knowledge to meet the needs of pupils (1987). In his 'Model of Pedagogical Reasoning and Action' (see Figure 1), Shulman summarised the practice that encouraged teachers to reason about their teaching and use their knowledge base to provide adequate ground premises for choices and actions. He makes particular reference to how teachers use ‘ethical, empirical, theoretical or practical principles’ to support pedagogical reasoning (pg.13).

The cycle of pedagogical reasoning begins with the act of comprehension and a critical understanding of the subject matter and how it connects to other subjects and ideas. Within this practice is a clear idea of the educational purpose(s) of what is to be taught and learned. This often involves interpretation of a text, for example, plans, a scheme of work or a curriculum programme of study. The comprehension of the content and purpose is only a pre-requisite to transforming the knowledge to forms that are ‘pedagogically powerful’ and adaptive to meet the needs of the pupils’ (pg.15).

Once the subject matter has been understood, ideas are then transformed and prepared for the comprehension of others, which Shulman refers to as the ‘act of pedagogical reasoning’. This process of transformation involves a critical examination and interpretation of the materials concerning the teachers’ subject knowledge (pg.16). He refers to this process as moving from a personal comprehension to preparing for the comprehension of others which requires adaptation and tailoring the materials to meet the needs of the learners. Table 1 identifies the characteristics required for adapting and tailoring the materials which include identifying misconceptions and contextualising the materials so that it considers language, culture and motivation of the learners. The transformation of content and subject knowledge is represented as approaches or strategies for teaching, which requires the teacher to use their pedagogical reasoning to inform how the teaching will take place - the instruction.

Table 1: Model of Pedagogical Reasoning and Action (Shulman, 1987 pg. 15)

Comprehension	Of purpose, subject matter structures, ideas within and outside the discipline
Transformation	Preparation: critical interpretation and analysis of texts, structuring and segmenting, development of a curricula repertoire, and classification of purposes. Representation: use of representational repertoire, which includes analogies, examples, demonstrations, explanations, and so forth. Selection: choice from among an instructional repertoire, which includes modes of teaching, organising, managing and arranging. Adaptation and tailoring to student characteristics: consideration of concepts, preconceptions, misconceptions, and difficulties, language, culture and motivations, social, class, gender, age, ability, aptitude, interests, self-concepts and attention
Instruction	Management, presentations, interactions, group work, discipline, humour, questioning and other aspects active teaching, discovery or inquiry instruction and the observable forms of classroom teaching.
Evaluation	Checking for student understanding during interactive teaching; testing student understanding at the end of lessons or units; evaluating one's own performance and adjusting for experiences.
Reflection	Reviewing, reconstructing, re-enacting and critically analysing one's own and the class's performance and grounding explanation in evidence.
New Comprehensions	Of purposes, subject matter, students, teaching and self. Consolidation of new understandings and learning from experience.

During the activity of instruction, the teaching involves observable performances of various teaching acts which are bound up with comprehension and transformation of understanding, as is the process of evaluation. The review of teaching and learning through reflection exposes new comprehension of the subject matter. Shulman states that although the processes in the model are presented in sequence they can occur in any order and some stages may not occur at all or are given less recognition during certain acts of teaching. For this study, greater consideration was allocated to the processes of comprehension, transformation, reflection and new comprehension.

Methodology

This action research presents a small case study that was carried out to critically evaluate a commercially produced STEM resource for use in a year 4 class. The main aim of the study was to improve practitioner knowledge and practice of integrating STEM across the curriculum. Yin describes a case study as an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-world context (2014). As an action research case study, systematic and critical analysis was carried out to understand what was happening in order to evaluate, then to introduce change and assess the new situation (Bassey, 1999). Action research is often considered to be emancipatory as it aims to improve practitioners' understanding and professional development (Zuber-Skerritt, 2005).

An interpretive approach was used to provide holistic descriptions and explanations for the particular phenomenon. The phenomenon for the study was expressed in the following areas for investigation. To understand and evaluate the contributions and the interdisciplinary approach of the four disciplines – Science, Technology, Engineering and Mathematics as presented in a commercial STEM resource. The multidisciplinary nature of STEM was critically evaluated at three stages during the research; at the start, partway through the teaching of the project and at the end of the project as a final evaluation. Each examination brought about a transformation to the plans and participants' thinking which identified some key features to consider when planning for a STEM-focused curriculum. The findings were cross-referenced and validated with interviews with the two participants. To improve practitioner Pedagogical Content Knowledge (PCK) and better understand the connection to the SDG, teaching and resources were evaluated and used to refine plans. Shulman's model of 'Pedagogical Reasoning and Action' was used with a particular emphasis placed on the use of the processes of comprehension, transformation, evaluation and reflection. As a result of the above areas of study, any subject knowledge issues that emerged from planning and teaching a STEM-based curriculum were observed for further action.

The participants in this collaborative study consisted of the year 4 class teacher (Lily), myself, a university researcher and mathematics tutor on an Initial Teacher Education programme and a representative from the commercial company who presented the STEM resource (George). All participants were considered equal in the research process and were involved at every stage. The communication that emerged during the study was considered to be 'symmetrical communication' whereby all communication shared by participants was on equal terms (Zuber-Skerritt, 2005). The school where the study was carried out caters for children from ages three up to nine years of age, many of which are from Military of Defence (MoD) service families. The school's approach to the curriculum considers STEM to be the cornerstone for learning where real-life implications through STEM teaching can be applied to everyday life. Lily took the lead on the science in the school and had an interest in developing subject knowledge in STEM and therefore expressed her interest in this research. George and I both have over 20 years of experience in primary education and teacher education. I have led on the teaching of primary mathematics in various capacities for 25 years and led the research. George has 20 years of experience in the use of information technology. Each participant had a vested interest in participating in the action research project; therefore, a commitment was voluntary and wholehearted.

Data Collection

The methodology employed in the study followed the qualitative research paradigm in which the researcher is part of the community under investigation. The research was conducted over a ten week period, during which data were gathered at various intervals. Data were obtained from multiple documents to include the notes of analysis at different stages of the planning process; I kept a journal of events, and notes from a staff meeting that explored the concept of STEM with all teaching staff. Three informal observations of the teaching of STEM lessons were carried out by myself, George and Lily. The purpose of the observations was to identify issues and themes for group discussions. The themes for group discussions were semi-structured to allow for ideas to be addressed that emerged and were presented through the observations. These discussions were digitally recorded and supported by participant notes on the planning document. Themes from the group discussion were used to develop and trial interview schedules that were carried out with the Lily and George. Qualitative data from the two digitally recorded interviews and group discussions. The transcripts were analysed using codes to categorise and identify key themes and patterns. Findings from documentations were scrutinised for their closeness of fit with the recorded data and used as a form of triangulation. A questionnaire involving six teachers was also used to provide an overall consensus on views and opinions on STEM education which further informed the planning process. The findings are organised around the areas for investigation. In the following presentation of findings, participants have been given pseudonyms to ensure anonymity

Results

1: Interdisciplinary approach across the four subjects

The analysis of the planning documents and records of the group discussions outlined the contributions and interdisciplinary nature of the four subjects as understood by each participant. The key finding indicated some unfamiliarity between knowing what the letters stood for in STEM and how to enact STEM in the classroom. The abbreviated letters' STEM' was understood by all participants in the context of what each letter represented. However, the implementation and enactment of STEM that was interdisciplinary across teaching were more complicated to comprehend. The reasons being we were not planning a subject but considering how to integrate four disciplines, sometimes this involved making connections to other areas of learning. This required depth of subject knowledge that considered the contributions made by all four subjects and knowledge of curriculum design and planning that embed the subjects purposefully for interdisciplinary teaching (Bell, 2016). Teachers struggling with enacting an integrated STEM curriculum and stepping away from individual subject teaching correlates with the study carried out by Blackley and Howell (2015).

The contributions of each disciplinary area were further impacted by how the three participants interpreted and viewed the plans. Lily interpreted the resource as it was presented. The connection and knowledge contribution across the four disciplinary subjects were given little consideration. Lily believed the resource to be a quality STEM plan because "*...it ... linked design and challenge with science*". During the first group discussion and reflections, it was noticeable that the commercial resource emphasised the role of design and technology (D&T) as a catalyst to drive the STEM agenda. Scientific understanding and application of the NC topic 'Living Things' was required to design the product, in this case, an invertebrate hotel

(DFE, 2014). Similarly, Lily also understood the STEM plan as 'product-focused' that involved an engineering design project as the culminating activity to a science unit.

The importance of curriculum design being central to developing an interdisciplinary approach across the four subjects was prioritised by George and myself. The process of aligning the STEM resource to the NC and planning for an interdisciplinary approach highlighted several gaps (see Table 2 Integration of STEM subjects in a curriculum plan). My engagement with research and literature at various stages throughout the study better informed the understanding of how the four subjects came together. The outcome identified a model for STEM planning that centralised engineering or D&T to manage the links to the other subjects in STEM (see Table 2 Integration of STEM subjects in a curriculum plan) (Blackley and Howell, 2015). This model of STEM is well-suited to the purpose of study for D & T as identified in the NC (DFE, 2014).

Table 2: Integration of STEM subjects in a curriculum plan

Sequence of lessons (themes)	Initial plan: Interdisciplinary links to STEM subjects	Final plan: Interdisciplinary links to STEM subjects
The challenge: The invertebrate investigation	Science - Understand the importance of invertebrates; common threats and food chain	Science (See the previous column) Technology - Demonstrate creativity; Communicate and collaborate; Conduct research and use information. Mathematics: Use and interpret data in science.
The design: what do invertebrate hotels look like?	Science - know the habitats of different invertebrates. D&T - use scientific knowledge to research criteria for an invertebrate hotel; Communicate design and share justification.	Science - (See the previous column) D&T - (See the previous column) Mathematics - use measures and understanding of area and perimeter of rectilinear shapes; engage in mathematics to solve real problems

Table 2: Integration of STEM subjects in a curriculum plan

		Technology - Conduct research and use information in the context of science inquiry.
Create the design	D&T - use a range of tools and equipment accurately; select from a wide range of materials and components for their functional properties to meet the design criteria. Science - know the habitats of different invertebrates.	Science - (See the previous column) D&T - (See the previous column) Mathematics - use measures and understanding of area and perimeter of rectilinear shapes; engage in mathematics to solve real problems
Evaluation and conclusion of the design	D&T - reflect in the design and build of the invertebrate hotel Science - recognise that environments can change and this can sometimes pose danger to living things.	Science - (See the previous column) D&T - (See the previous column) Technology - Demonstrate creativity; Communicate and collaborate; use technology effectively and productively.

The lack of guidance and expert knowledge on how to plan and teach STEM can easily mislead teachers to view STEM as a D&T project with no or limited integration of knowledge across the four discipline areas as it did in this incident. The transformation required from understanding the resource to the planning and teaching stage involved a depth of subject knowledge to be cognisant of the contributions made by the four disciplinary subjects.

Understanding the structure of subject matter, depth of knowledge and the principles of how that understanding is communicated is identified by Shulman (1987) as 'scholarship in content disciplines' (pg. 8) one of the four major sources for the teaching knowledge base. The process of going back and forth to review literature and empirical research in this area of learning supported the design of the curriculum that connected the four subject areas as well as other aspects of learning. George commented on the '*possible deskilling of teachers in knowing how* *to design their curriculum ... and therefore, not having the confidence or comprehension to take ... the STEM resources and do something powerful with them'*. My observations are in alignment with George, the planning task of designing a STEM curriculum highlighted two main issues. Firstly, the importance of subject knowledge required across the four disciplinary subjects to integrate STEM in a unified way. Secondly, the importance of scholarship and literature around STEM education to have a deeper conceptual understanding of what constitutes as ‘good’ STEM education (Shulman, 1987).

The lack of professional development and support for primary practitioners to integrate STEM learning within a primary curriculum was highlighted by all three participants. Lily indicated that as a school they built on ideas that they may have found on the internet and expanded on them, but they were not aware of resources or units of work that made links across the four disciplinary subjects or to the NC. The analysis from the questionnaires sent to the staff indicated a similar picture. Although teachers valued STEM education, they were unsure how to develop a STEM idea over a sequence of lessons that linked all four subjects as well as the broader curriculum and needed some guidance on how to do this competently.

2: Pedagogical approach

All three participants believed that an inquiry-based approach to learning and teaching was most effective in communicating the STEM agenda. All three practitioners agreed to the inclusion of the following 21st Century learning skills - collaboration, creativity, communication and critical thinking on the plan. Incorporating these skills in every lesson further informed the instructional repertoire, structure and organisation of learning during lessons.

All participants understood that an inquiry-based approach to learning promoted a student-centred pedagogy and as a result informed how children were organised for learning. Group work worked particularly well as it encouraged children to develop skills of collaboration and communication. For example, during each STEM session '*...the problem and challenge was designed to motivate children to think about the issue. Organising children in groups worked as they are learning with each other and from each other'* [Lily].

All three participants identified the skills of creativity and critical thinking as being less successfully reinforced during learning; this was due to how closely the plan was followed to deliver the content. The inquiry-based instruction was 'structured' in that students were provided with a hands-on problem to solve as well as the procedure and materials to solve it. Lily found the 'r*esource offered a useful scaffold for teachers to follow'*. However the structured nature in which the lessons were organised hindered creativity and critical thinking at times as children were led to a particular solution. This supports Shulman's (1987) view that teacher comprehension is even more critical for the inquiry-based classroom than it is for the didactic alternative. George commented that,

> '*a less confident teacher may not bring in some of the higher-level learning or critical thinking for students to naturally apply all the science, maths and technology they would need to create and make a project. The first lesson kind of gave it away and because it gave too much information it took the power from the children to be problem solvers, instead they were told what they were doing which is a little wrong with the whole concept of what STEM is*'.

All three participants agreed that the pedagogical approach to inquiry-based learning needed to be a mixture of 'guided inquiry', in some incidences, with the teacher providing materials to solve the problem to investigate and allowing students to devise their own procedure, and an 'open inquiry' where students formulate their question to investigate. George and I emphasised the use of question stems framed around Bloom's taxonomy of learning to support critical thinking and to promote a more open inquiry approach to teaching and learning. *'…key questions related to Bloom's taxonomy are also useful lines of inquiry for the teacher'* [George].

I emphasised how the design cycle and product-focused agenda promoted by the STEM resource overtook the learning and experiences for the students, '*the purpose and reason for the STEM project got a little lost after the first lesson… the meaning of the project and how it connected to real-world issues became a little fuzzy*'. George and I felt the need to return to the SDG at various stages of the learning process to further children's creativity and critical thinking. I suggested 't*he SDG should be central to the learning and lead the whole unit. The SDG encouraged learning in a real-life context and considered local as well as wider global issues that are important. They also empower young people to think about global issues'*. George and I saw how the SDG was purposeful and could be applied to encourage students to consider the challenge in the context of social, ethical, economic and environmental perspectives. The involvement of local external experts who work in the field of conservation would have been another useful contribution to contextualise the learning to real-life issues for investigation.

The resource was titled 'Invertebrate Hotel', and all three participants agreed the title for the resource should be a question based around SDG 15 'How do you protect local terrestrial ecosystems and biodiversity?' Lily pointed out the resource emphasised designing a 'hotel' which led to misunderstanding the purpose of the design project, a hotel is temporary and as conservationist students needed to consider long term solutions which are real and most familiar to the students' context.

3: Pedagogical Content Knowledge (PCK)

STEM Pedagogical Content Knowledge (PCK) was a dominant theme that emerged from all data collected. The significance of PCK has been mentioned in previous findings. However, I want to discuss the contribution of PCK in the context of input offered by the three participants and the resource.

All three participants found the resource to be a practical and '*…a good scaffold…'* [George] to support PCK in STEM. Lily spoke about the '*structure of how STEM was presented and the supporting activities that were convenient and purposeful*'. The area of the curriculum that Lily and I found most challenging was aligning technology to the NC. This was because NC does not have technology as a subject; instead, it refers to Computing. Lily referred to linking the technology as being '*tricky*' in the context that *'we teach science and maths, but we don't teach technology'*. She felt she lacked the knowledge and skills to fully embed technology as part of the STEM plan. I also found the Computing programmes of study in the NC restrictive to how technology could be used in the context of STEM. George and I drew attention to how a teacher who maybe insecure in STEM knowledge, not necessarily make the links across the four disciplines. *'It does raise some subject knowledge issues, … it is a different way to teach, which is not about compartmentalised subjects, and that's not easy to do*' [George]. I also spoke about some missed opportunities to bring in the maths and technology during the teaching.

The collaboration of the three participants was an interesting amalgamation as each viewed STEM differently. All three participants valued the contributions offered by each. Lily spoke about '*sharing ideas and drawing upon everyone's subject expertise*'. George mentioned the usefulness of the literature that helped drive this research as well as the expertise shared by each participant. Each participant was able to comprehend and transform a discipline in STEM and make connections to other areas because they had a ‘deeper’ understanding of the subject matter.

The contribution of mathematics as understood by the different participants was an interesting observation. The resource had very little reference to the contributions made by mathematics. I felt the connections to mathematics was simplistic and rudimentary. What was lacking was the application of the subject through the teaching of science and D & T. Various opportunities were lost where the application of mathematics could have been used to reason the scientific knowledge and D&T process.

Discussion and Conclusion

New Comprehensions

‘Thus, we arrive at a new beginning’ (Shulman, 1987). This small-scale action research study offers valuable insight into how STEM is understood by different practitioners and how that knowledge is used to inform curriculum development for STEM education. Although a national definition and understanding of STEM education might be difficult to achieve, I would argue that each school needs to have a clear understanding by what they define as STEM education as enacted in their schools through curriculum planning. To enable teachers to do this, resources and investment in teacher education is vital. I argue that a lack of professional development in the four disciplinary subjects and knowledge of knowing how to connect the subjects in an interdisciplinary manner limits teachers’ potential to create STEM education in their classrooms.

Much of the funding and professional development in education is orientated towards support for Higher Education institutes and secondary schools to increase the number of students pursuing STEM subjects, and to ensure students were well-prepared and suitably qualified to engage in STEM careers (McDonald, 2016; Ejiwale, 2013). Many of these initiatives are based on secondary education to aid entry into Higher Education courses. However, research has identified a greater STEM focus in the earlier years of schooling. Hudson et al. (2015) argue that competencies to active engagement in STEM require an extended period of time and that STEM education should begin in the Early Years and primary education. They argue that primary schools have an essential role in ensuring that they are providing a supportive teaching and learning environment cultivating the skills and competencies required for active STEM engagement that is necessary for the post-compulsory years of schooling and beyond. I argue that teacher professional development in areas of STEM is crucial for a comprehensive and critical understanding of the subject matter related to STEM and how it connects to other subjects and ideas.

The relationship and contributions of each subject discipline within STEM, as understood by practitioners, impacted on how it was planned for and enacted in the classroom. I draw upon the work of Lawrence Stenhouse, a pioneer of the idea of curriculum development as the basis of in-service professional education (Fordham, 2016). He was interested in how teachers designed curricular that improved pedagogy rather than teachers working out how to deliver a curriculum. The experiences of Lily and George in teaching STEM was to deliver a curriculum plan. Although this research began with a pre-planned curricular resource, through collaborative practitioner-researcher, the curriculum evolved. It enhanced the understanding of 'interdisciplinary' between the STEM subjects (Annan-Diab and Molinarib, 2017 p. 4). It widened that knowledge to encompass the ethical and philosophical aspect of the impact of STEM in society as well as increase knowledge in understanding complex real-world problems in relation to the SDG. The commercial plan provided a structure and scaffold that was valuable for the teacher. Lily had a starting point, and from this starting point, she was able to 'transform' learning for her class and her situation.

One of the outcomes of this study identified professional development for Lily. The study made Lily aware that some areas of her practice required further education and professional development. Reflections on pedagogical subject knowledge that emerged were considered further with other teachers across the school, an example being reviewing the role of technology and how it was used across the curriculum. My discussions on the application of mathematics, in this project, coincided with the research the headteacher was doing, which identified a similar outcome.

The collaboration of the different practitioners within the planning process changed thinking on the idea of STEM to initiate a product-focused model. It also changed pedagogical practices on how STEM was taught in the classroom. The 'hidden' aspects of technology and mathematics in this resource could easily have been missed without the input from subject specialists. I would argue for partnerships between schools and education departments in higher education to facilitate learning communities that support innovation and change in education. I would also argue that commercial education agents work alongside higher education to ensure that products are based on sound research and embedded in the theory of learning and teaching before they are marketed to teachers.

As interest in STEM education grows in primary and Early Years settings so will the marketisation of products for teachers to deliver the initiative. With the misalignment of STEM with the NC and the challenges of defining STEM, further research in this area of learning and teaching is highly recommended. It is to be noted that this is a small-scale case study. However, the findings from this case study facilitated a further cycle of action research that involved the whole school. This one example was used as a model to develop curriculum planning across the school with other teachers. The other important factor that would enhance this study would be explore responses and feedback from students.

There is universal recognition that teachers researching their own practice can generate unique ‘insider knowledge’ that provides valuable new insights and conceptualisations of educational processes and practices, (Burke and Kirton, 2006). This study can be used as a model by other schools as a starting point when considering implementing STEM education. Expanding this research to consider different approaches to STEM curriculum design would be valuable and that ‘insider knowledge’ of comprehension and transformation of pedagogical knowledge will further the understanding of STEM education in primary school settings.

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